Salmon Spawning Gravel Enhancement Studies on Northern California Rivers

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ABSTRACT: As part of the Resources Agency's Resource Investment Fund and the Wild and Scenic Rivers Program, the California Department of Water Resources (DWR) is studying spawning gravel enhancement techniques and locating potential new spawning areas in six California rivers (Fig. 1). The purpose of the studies are to (1) determine the effects of watershed and hydrologic changes on salmonid spawning and holding habitat; (2) locate areas suitable for artificial gravel placement and other enhancement work; and (3) develop management alternatives for each river. Three studies have been completed. These are the Sacramento River between Keswick Dam and Red Bluff (Parfitt and Buer 1980), the Klamath River between Iron Gate Dam and Humbug Creek, and the Shasta River between Lake Shastina and the mouth (Buer 1981). Construction of these proposed spawning areas would provide for an additional 70,000 salmon pairs. Similar studies are in progress for the Feather River and the Wild and Scenic portions of the South Fork Trinity and Middle Fork Eel rivers.

Introduction

The anadromous fishery has made a substantial contribution to the Northern California economy for many years, augmenting both the sport and commercial fisheries. However, salmon spawning escapement in many streams has declined dramatically over the last century. There are many reasons for this, including dams, diversions, overfishing, major floods and droughts, gravel extraction, timber harvesting and attendant watershed degradation. Each river system differs in watershed characteristics and the specific causes of its fishery problems.

The upper Klamath River, the upper Sacramento River, and the Shasta River were once primary chinook salmon *(Oncorhynchus tshawytscha)* spawning rivers. Few salmon now spawn in the reach below Iron Gate Dam on the Klamath River, and Shasta and Keswick Dams on the Sacramento River because the riffles are now armored by cobbles too large for salmon to move. This is due to loss of gravel recruitment from areas above the dams, to channel degradation and to scour of spawning gravel below the

dams during high flows. Gravel extraction for aggregate has reduced tributary input. There are similar gravel recruitment problems, high water temperatures, and siltation and irrigation diversions on the Shasta River. The Feather River below Oroville Dam is now being studied to determine what problems exist there.

The South Fork Trinity and the Middle Fork Eel rivers are both wild rivers without dams. Both were among the better salmon and steelhead streams in California and among the few streams in Northern California that support spring-run steelhead *(Salmo gairdneri)*.

Both rivers were severely damaged during the December 1964-January 1965 flood. The flood, estimated to be a 100-year event, caused extensive bank failures, landsliding, and stream aggradation. In some areas, severe watershed damage was linked to the cumulative effects of areas logged before the flood (Scott, et al. 1979). Twenty to thirty feet of channel aggradation was common after the flood. This reduced the number of summer holding pools, degraded summer steelhead habitat, and silted in spawning gravel.

FIGURE 1. *Northern California with dots showing the locations of spawning gravel enhancement and stream geomorphology studies by the Department of Water Resources, Northern District Geology Section.*

The fish runs on the Middle Fork Eel River appear to be returning but runs on the South Fork Trinity River have not recovered.

Methodology

Each river system has its unique problems of hydrology, stream geomorphology and fisheries. However, these rivers are similar in that a reduc-

tion over historic levels of adequate fish habitat has occurred. As a result of these studies, California Department of Water Resources (DWR) has developed an investigative methodology for evaluating spawning gravel and enhancement techniques. These techniques are applicable to other salmon spawning streams in California and include:

1. Making an aerial photo atlas of the

study reach.

2. Compiling historic spawning, channel morphology and watershed data.

3. A spawning gravel survey using bulk and surface sampling techniques.

4. Analyzing streamflow data to determine the hydrologic characteristics.

5. Identifying and surveying potential enhancement areas.

6. Calculating critical discharge for bedload movement and the gravel bedload budget.

7. Recommending suitable enhancement sites.

Aerial Photography

Nine by nine inch aerial photos with a scale of 1:24,000 or 1:12,000, are taken of study areas. The photos are enlarged to 1:6,000 for the 11 x 17'' atlas sheet. River mile, a scale and a north arrow are shown for convenience.

The aerial photo atlas is used in the field to plot stream survey data, stream meandering, suitable spawning areas, and landslides. In addition, bank protection, blockages, riprap and unstable banks are plotted. To evaluate geomorphic changes such as stream meandering and landslide densities, data obtained from historic aerial photos and survey maps are plotted on the atlas. Historic spawning areas are also plotted

where these areas have been located.

Hydrology and Stream Channel Gravel Characteristics

Stream hydrology is used to plan and design fishery enhancement structures and to determine the gravel bedload budget. Data developed from stream gage measurements include annual yields, mean and peak monthly flows, flood flow frequency analyses, and flow duration curves. Stream flow diagrams were developed for each stream and its tributaries, showing average yields for the four seasons.

The annual yields show the dry and wet years on record. The mean and peak monthly discharges are characteristic of a particular watershed. The hydrographs show large variations in flow, both during and between the years, reflecting the precipitation pattern, snowmelt and watershed characteristics. The peak monthly flow is the highest mean daily discharge for the month. This shows the flood events on record. Stream character and salmonid escapement are affected by these floods.

Flood frequency diagrams are used to predict the flood magnitude expected within a given number of years and to rate the floods that have occurred in the basin. The reliability of these predictions depends on the length of record. Table 1 shows the recurrence intervals derived from the frequency diagram for recent floods on the Klamath and Shasta rivers.

TABLE 1. *Average daily flow during recent floods.*

Date	Klamath R below Iron Gate Dam ft³/s	Recurrence interval in years	Shasta R near Yreka ft³/s	Recurrence interval in years
Dec. 64	25,000	25	10,400	50
Jan. 70	12,700	4	4,010	8
Jan. 71	6,040	1.5	1,300	2
Mar. 71	10,600	3	1,290	2
Mar. 72	16,200	7	2,280	4
Jan. 74	16,000	7	5,800	14

Flow duration curves show the percent of time a specified discharge is equalled or exceeded. These curves are necessary for calculating the gravel budget and useful for designing enhancement structures.

Many methods have been used to determine stream channel gravel characteristics. These include surface sampling, bulk sampling, and freeze cores. Bulk sampling and surface sampling were used for these studies, since freeze cores were too expensive and slow for large project areas.

Sieve analyses and the frequency distribution of the gravel sizes are used to determine the size suitability of the gravel for spawning. Statistical parameters useful for describing sediment samples are then calculated. These include the median, geometric mean, standard deviation, skewness and kurtosis.

The gravel budget is calculated by comparing hydrology to gravel characteristics, surveyed cross-sections, and other stream properties. These data are used in bedload transport formulas to determine the gravel budget.

The formulas used are the Schoklitsch, and Myer-Peter and Muller (MPM) equations (Vanoni 1975). Critical transport discharges (the flow where spawning-size gravel begins to move) are estimated by comparing flows with gravel movement and integrating to zero transport. Velocities were estimated using the Manning equation, gaging station data and direct measurements. These velocities are then compared to the Hjulstrom (1935) diagram as another estimate of initial movement (Fig. 2).

The Schoklitsch equation (Vanoni 1975) may be expressed as:

$$G_S = \Sigma\, pi \quad (25.3) \quad \frac{(95.56)\ S^{1\cdot2}}{\sqrt{dsi}} \left(\frac{Q}{W} - .638\ \frac{dsi}{S^{4\cdot3}} \right) IW$$

where
G_S = bedload transport in yd^3/yr
pi = weight fraction of sediment samples of a particular size range
dsi = mean diameter of pi in feet
S = energy slope
Q = discharge in ft^3/sec
W = width in feet
I = interval that a particular Q occurred during a 100-day period

The calculation is repeated for the different combinations of pi and Q. The MPM equation in the foot-pound-second units is:

$$G_S = 9.67\ [3.306 \left(\frac{Qs}{Q}\right)\left(\frac{D_{90}}{ns}\right)^{1\cdot2} rS - .627\ D_g]^{1\cdot2}\ IW$$

where
n_S = roughness coefficient
r = hydraulic radius
D_{90} = gravel diameter at 90th percentile
D_g = mean gravel diameter
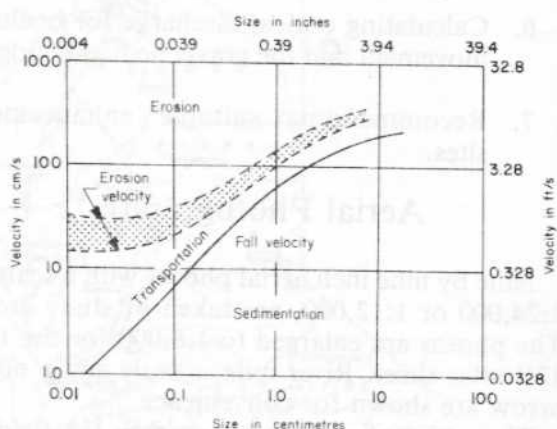$\dfrac{Q_S}{Q}$ = ratio of critical discharge to discharge

FIGURE 2. *Curves of erosion and deposition for uniform material. Erosion velocity shown as a band. (Redrawn from Hjulstrom 1935).*

Enhancement Sites

Potential enhancement sites are identified by comparing stream gradients, critical flows, stream morphology, and gravel stability characteristics. The recurrence interval of critical flows determines the advisability of placing imported spawning gravel in the stream channel. The ten-year flood is used as a design criterion. If critical flows occur at less than ten-year intervals, retention structures such as rock or gabion weirs, deflectors, groins or dikes are recommended; instream enhancement is generally not advisable in such a case, and side channel development is preferable.

Side channel enhancement site selection is

based on stream morphology, access, available spawning gravel near the site, environmental impact, flood flow routing and excavation needs (Fig. 3). Instream enhancement sites are selected according to gravel transport equations and accessibility.
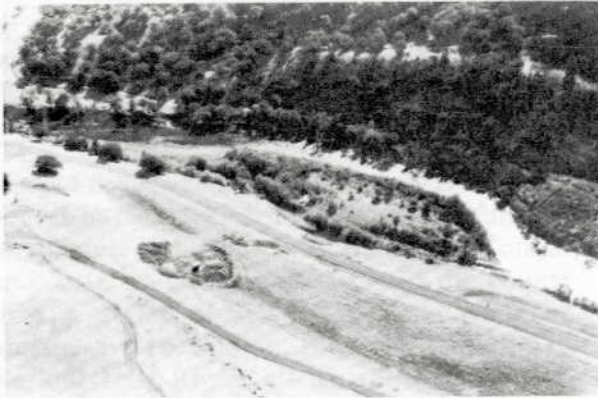

FIGURE 3. *Potential side channel enhancement site on the Klamath River. The site is protected from high flows that scour gravel in the main channel.*

On the Klamath and Shasta Rivers, seven and five sites respectively, were surveyed. An additional 14 sites were identified but not surveyed. This represents a potential increase in available spawning area to accommodate an additional 25,000 spawning pairs (Table 2).

TABLE 2. *Potential increase in available spawning area.*

River	Area (ft²)	Number of spawners
Klamath		
Instream	500,000	24,000
Side channel	200,000	9,000
Shasta		
Instream	300,000	14,000
Side channel	80,000	3,000
Total	1,080,000	50,000

Similarly, on the Sacramento River, enhancement sites capable of supporting 44,000 spawning pairs were identified.

Enhancement sites were surveyed using transit, chain and rod. The cross-sections are plotted and a contour map and longitudinal profile of the channel thalweg for each site is drawn.

Design and construction methods differ between instream and side channel enhancement sites. Instream sites may degrade during flood flows, are generally more difficult to get to, and present problems with using equipment in deep or swift water. Construction requires placement of gravel and retention structures. Side channel sites require excavating portions of the channel and importation and placement of graded gravel. For side channel work, a weir may be placed across the upstream portal to control flows during and after construction. Downstream from the weir, gabions or rock weirs may be placed in a series of steps to create a pool-riffle sequence and control the gradient.

During the fall of 1980, DWR, in conjunction with California Department of Fish and Game and California Conservation Corps, constructed three enhancement structures on the Shasta River. These included a rock-filled gabion weir (Fig. 4), a buttressed rock weir and a low rock weir. The purpose was to evaluate the effectiveness of different spawning gravel retention

FIGURE 4. *Salmon Heaven instream enhancement site on the Shasta River. Low gradient and wide channel reduce flow velocities. Gabion was installed to trap gravel and provide additional spawning habitat.*

structures during high winter flows. Gravel trapped behind the weirs would also be a measure of gravel movement in the Shasta River. Gravel was also placed behind the weirs to see if spawning would occur. Finally, spawning activity on the emplaced gravel was evaluated. Approximately 3000 ft² of new spawning area was created by this project. No salmon spawned at the site before the project, but an estimated 60 redds were counted in the new gravels in the fall of 1980.

References

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